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Colli

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(54) **SENSING APPARATUS**

(71) Applicant: **EMBERION OY**, Espoo (FI)

(72) Inventor: **Alan Colli**, Cambridge (GB)

(73) Assignee: **EMBERION OY**, Espoo (FI)

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H01L 31/113 (2006.01)
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See application file for complete search history.

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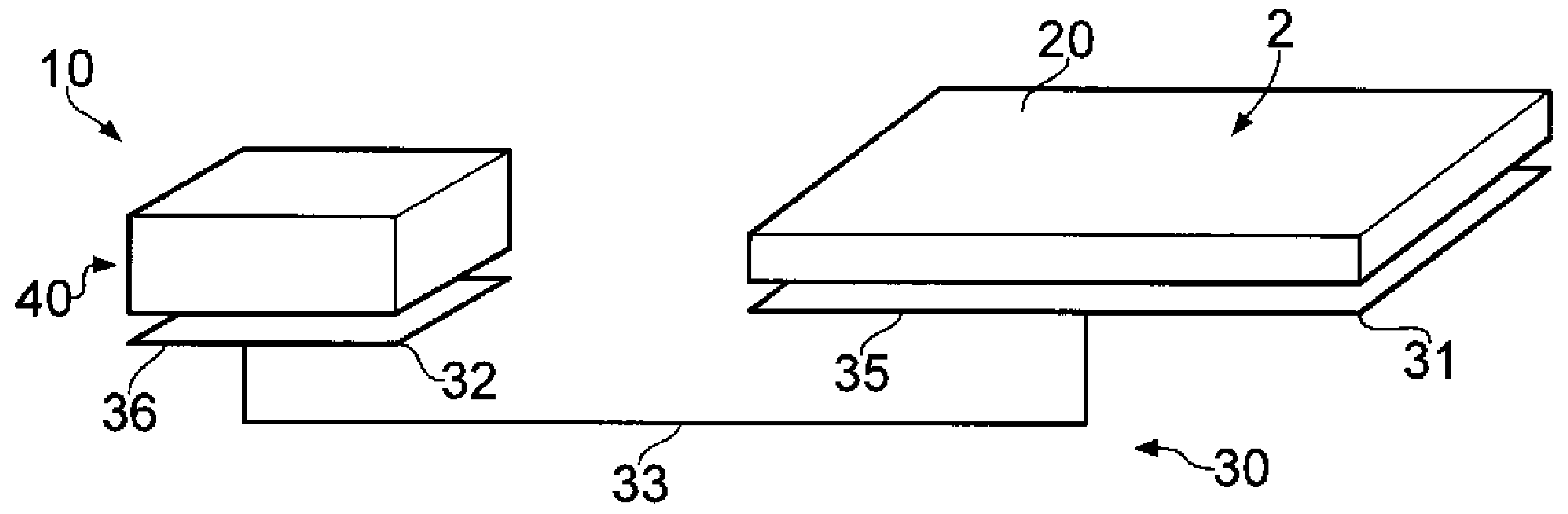
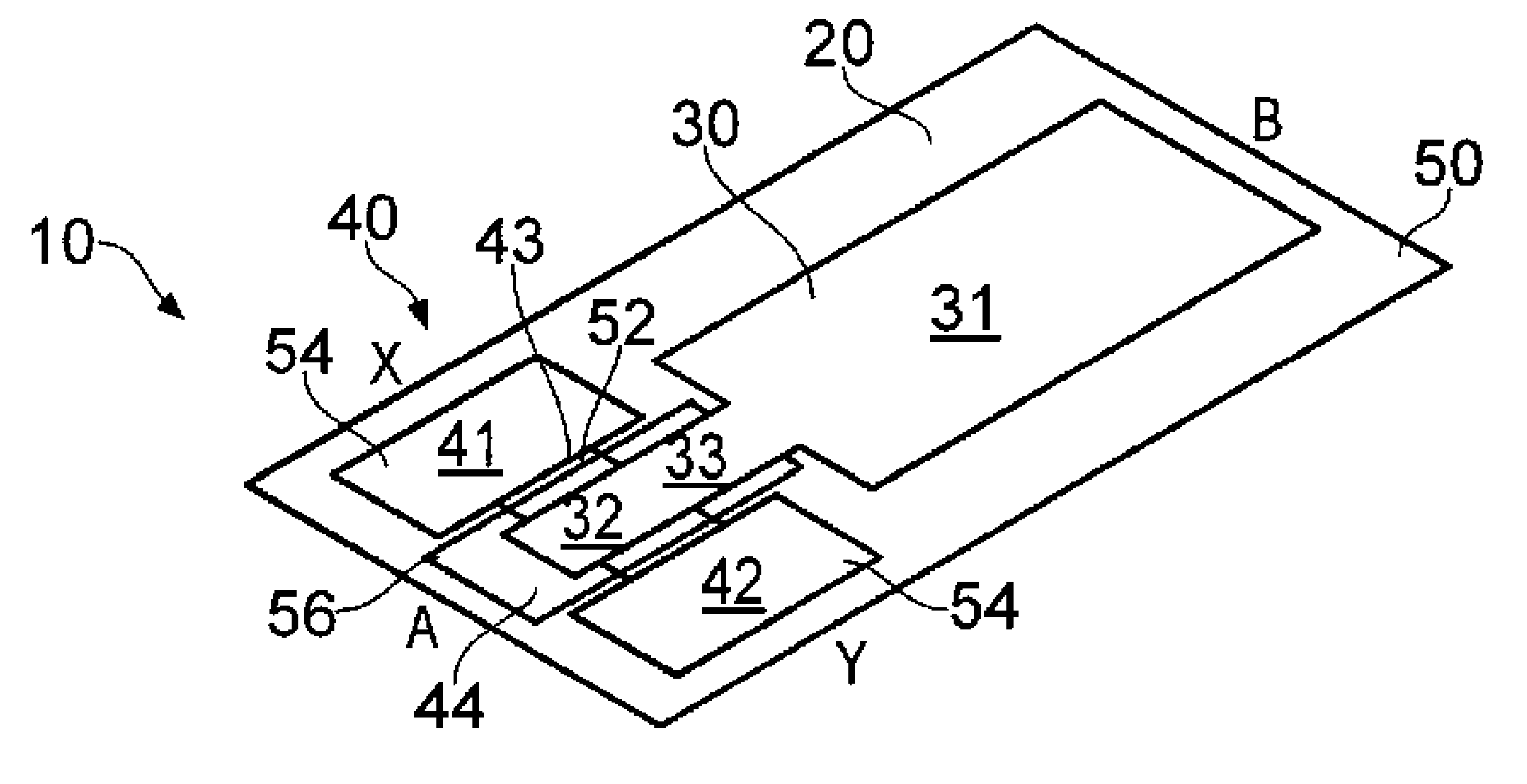
Primary Examiner — Yara B Green
(74) *Attorney, Agent, or Firm* — Squire Patton Boggs (US) LLP

(57) **ABSTRACT**

An apparatus comprising: pyroelectric material; an electric field sensor; a first conductive electrode comprising a first area adjacent the pyroelectric material; a second conductive electrode comprising a second area adjacent the electric field sensor; and a conductive interconnection between the first conductive electrode and the second conductive electrode, wherein the first area of the first conductive electrode is larger than the second area of the second conductive electrode.

8 Claims, 4 Drawing Sheets





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G01J 5/34	(2006.01)
H01L 29/423	(2006.01)
H01L 29/778	(2006.01)
H01L 29/16	(2006.01)
H01L 31/0352	(2006.01)
H01L 31/119	(2006.01)
H01L 21/04	(2006.01)
H01L 29/786	(2006.01)
H01L 29/40	(2006.01)

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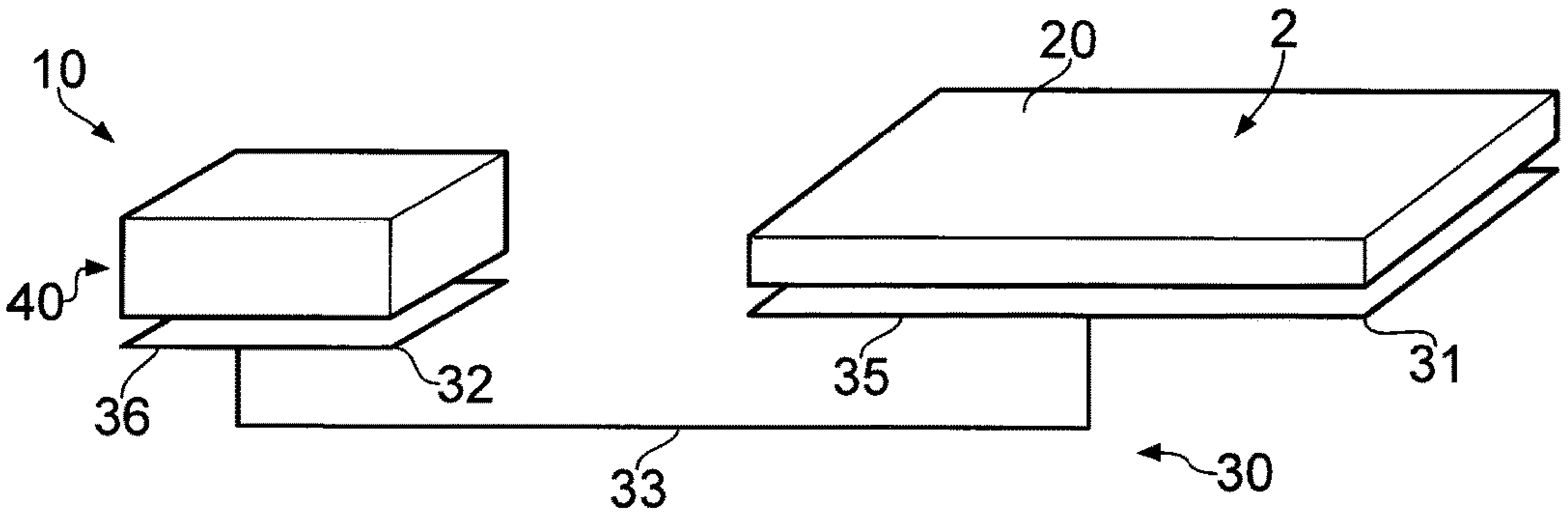

FIG. 1

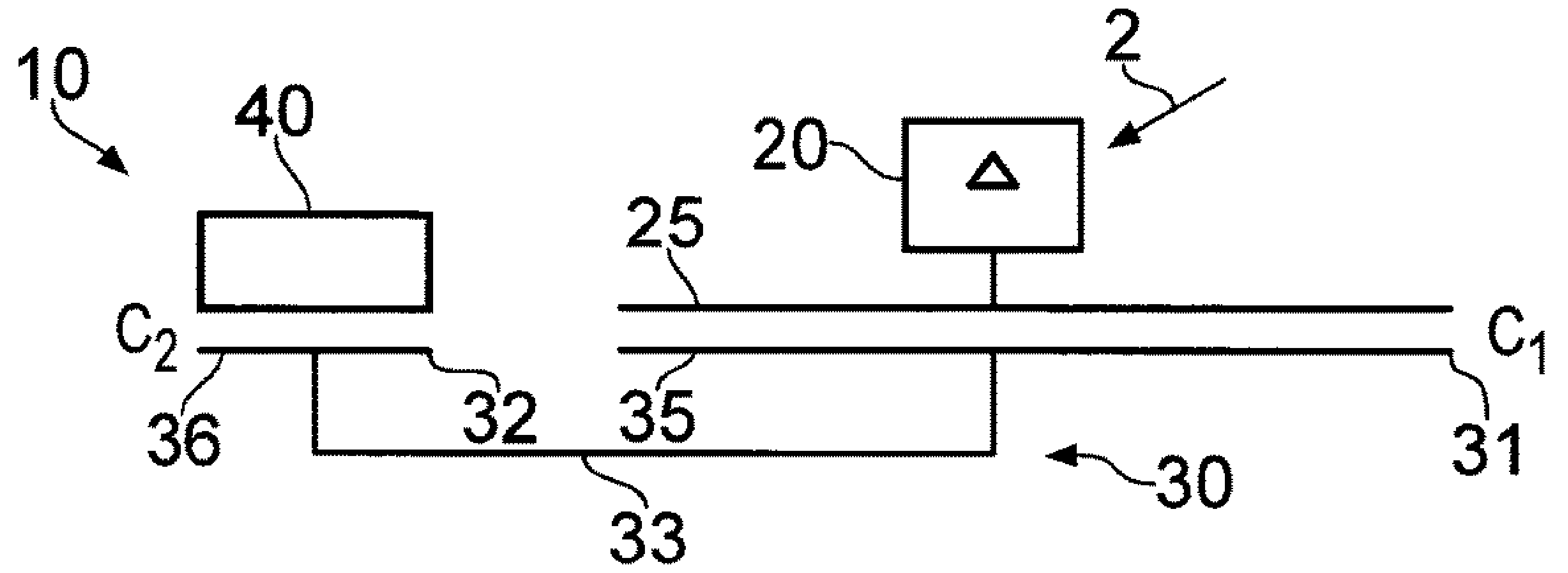

FIG. 2

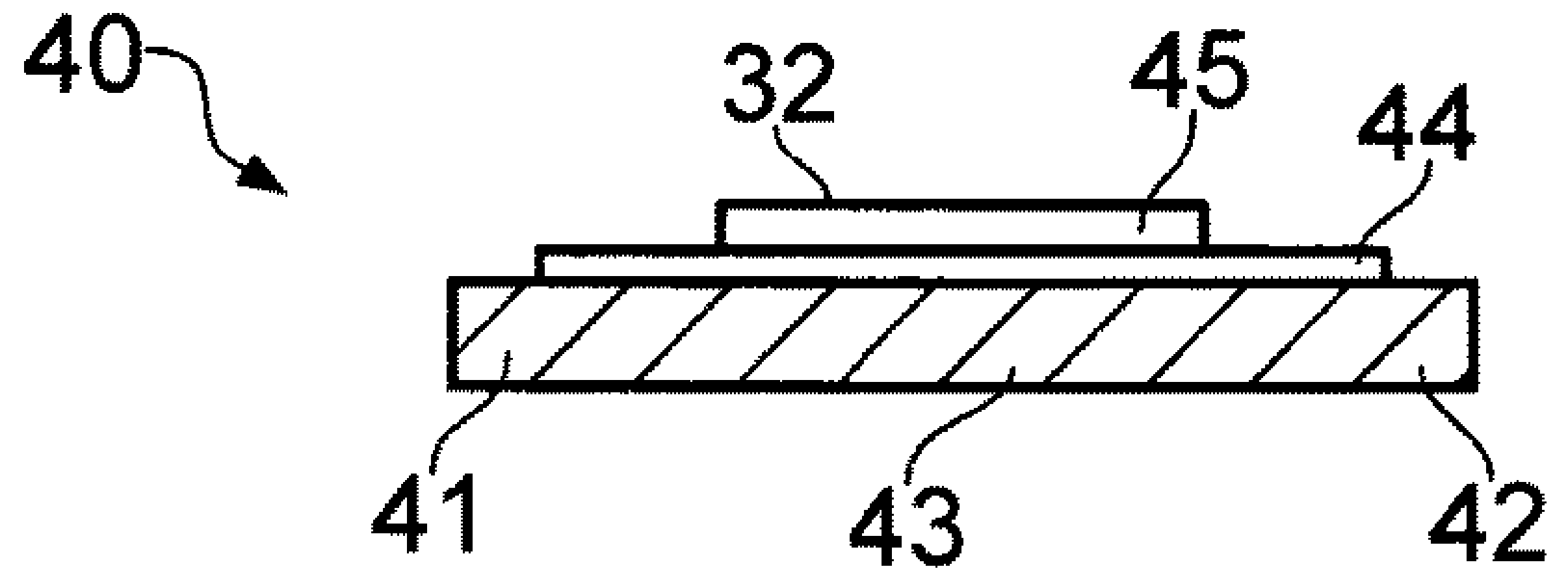

FIG. 3

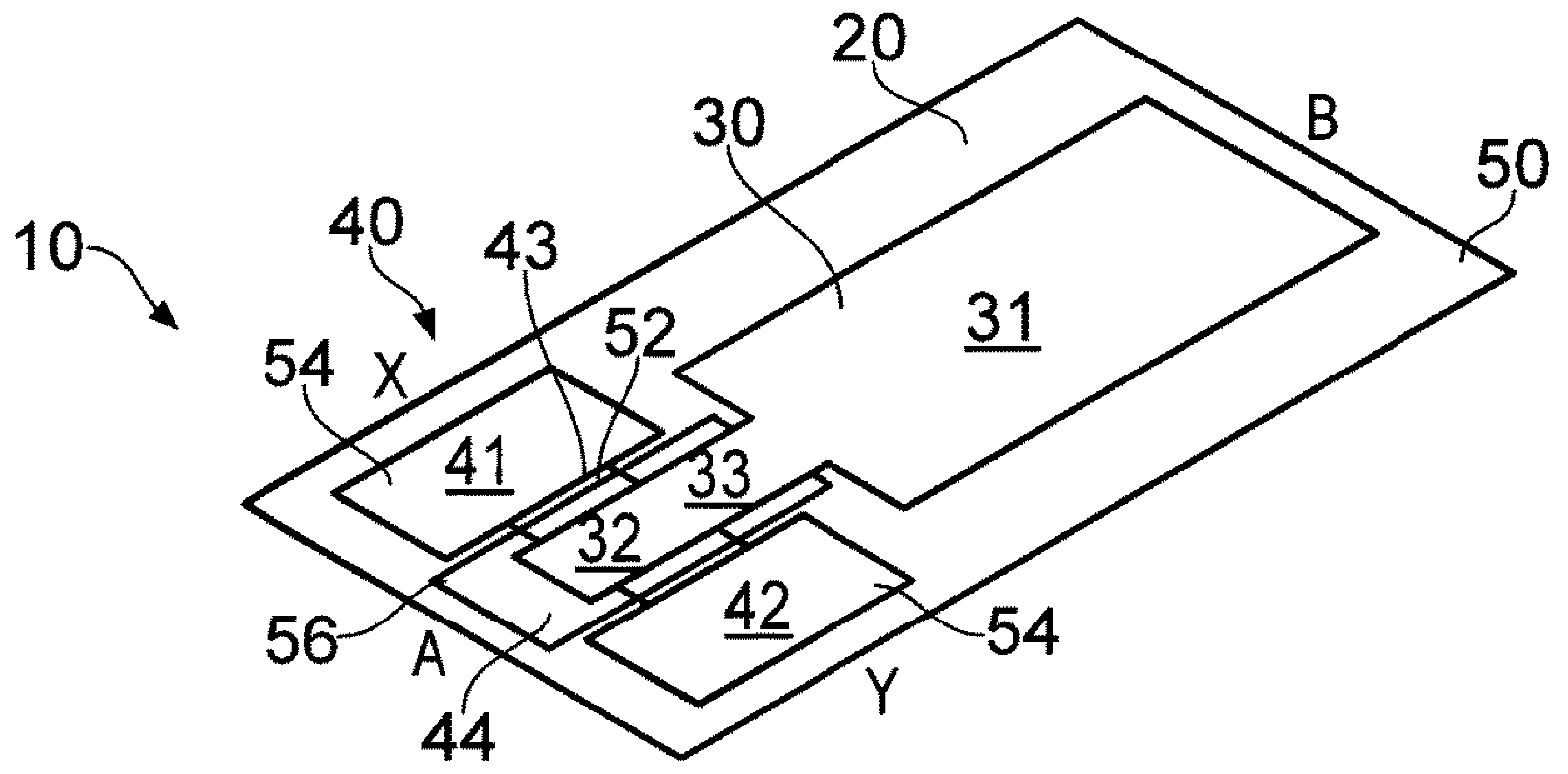

FIG. 4

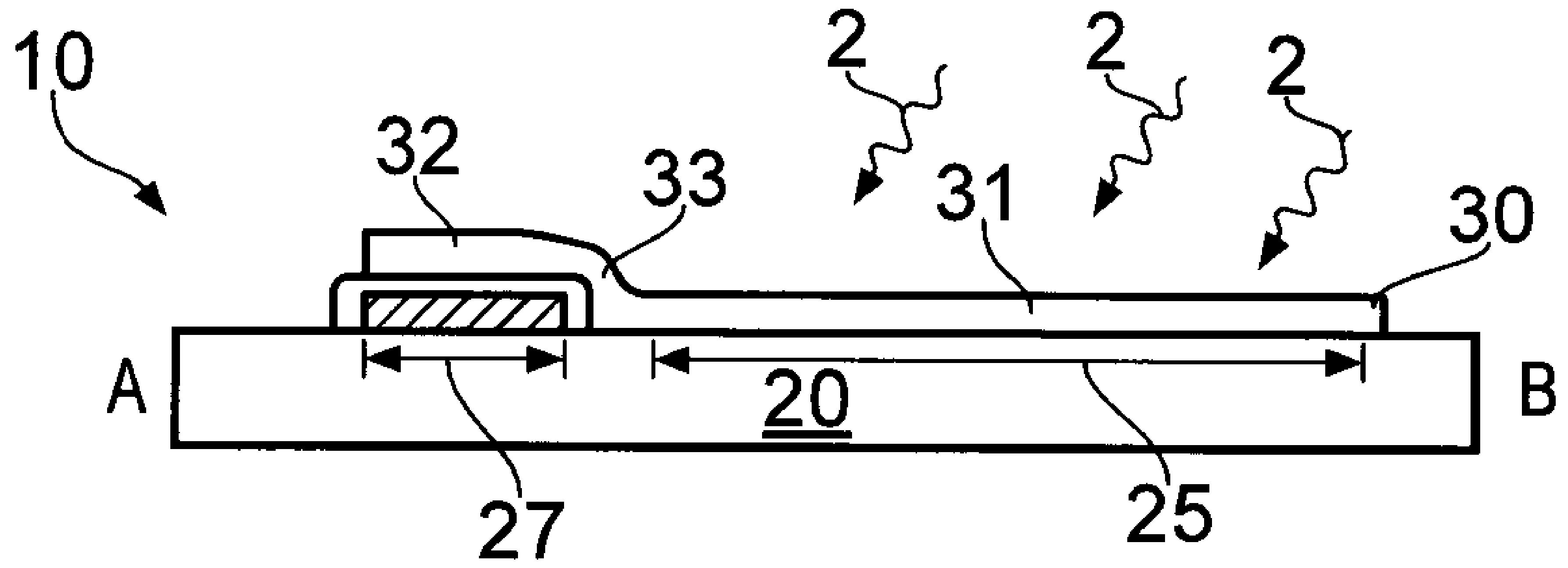

FIG. 5A

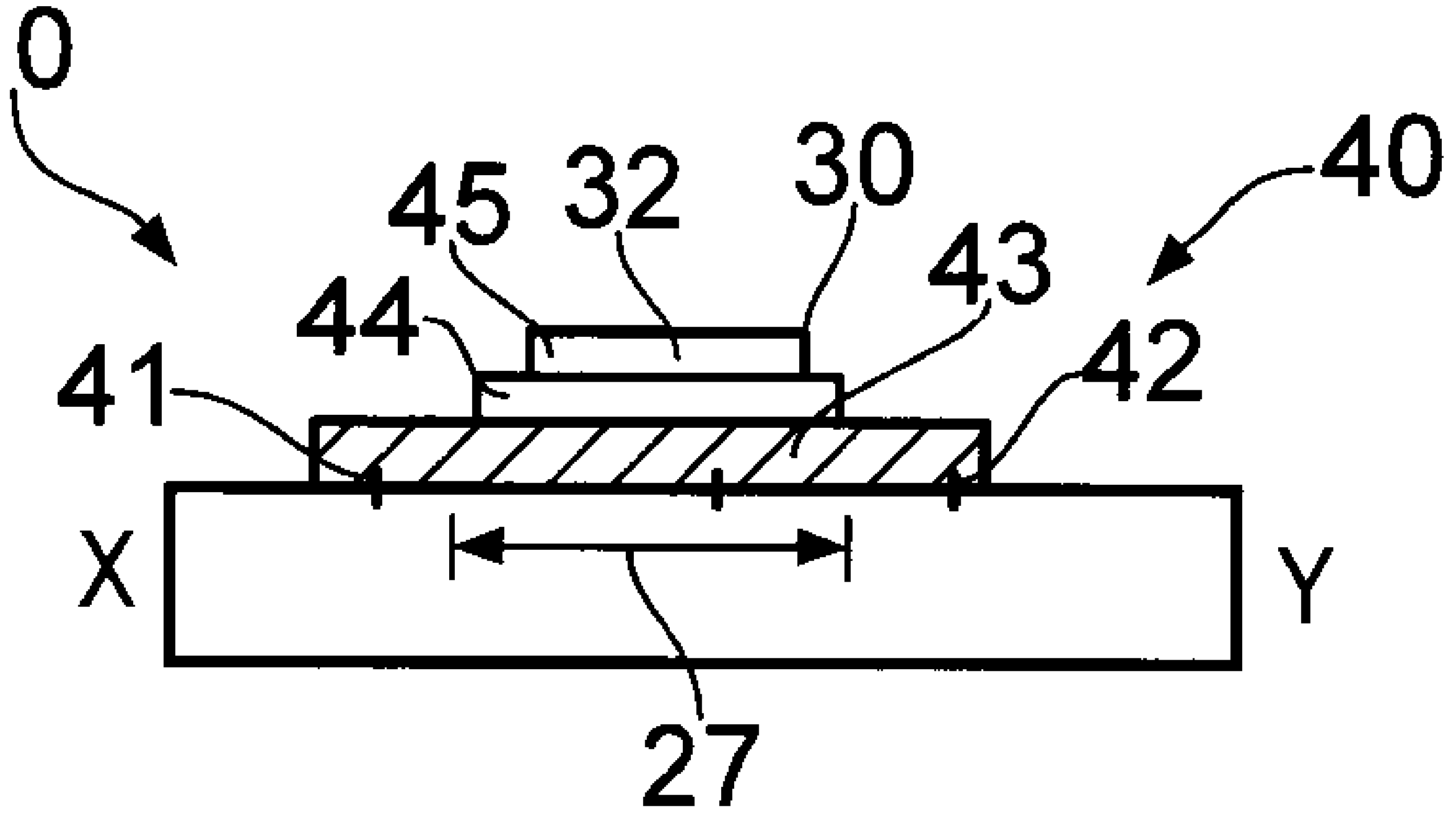

FIG. 5B

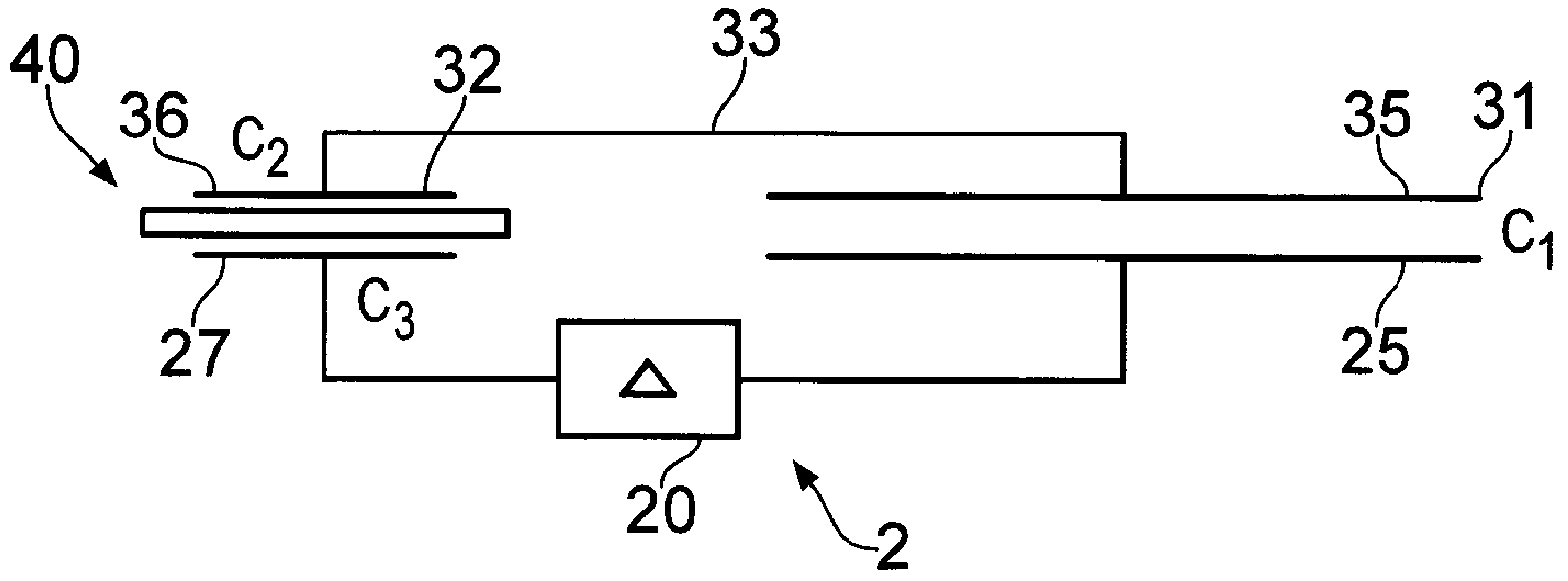

FIG. 6

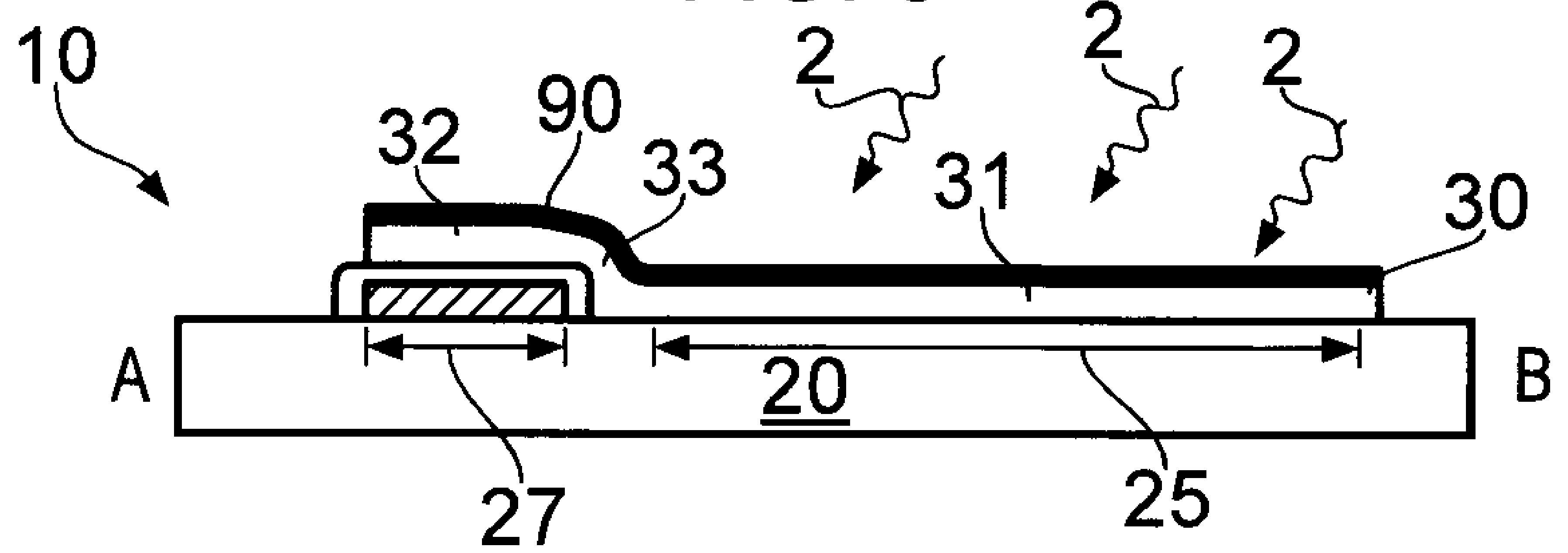

FIG. 7A

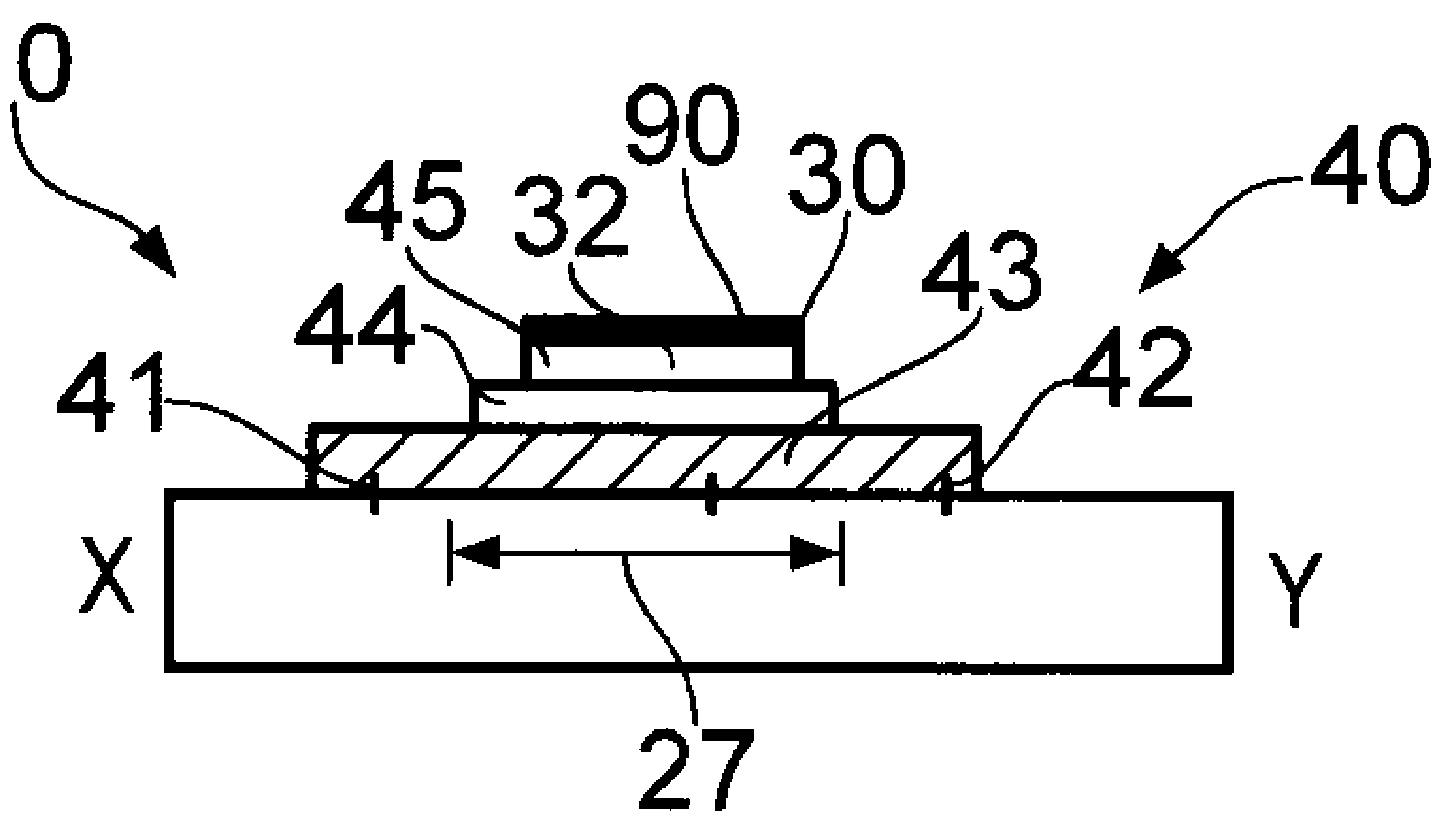

FIG. 7B

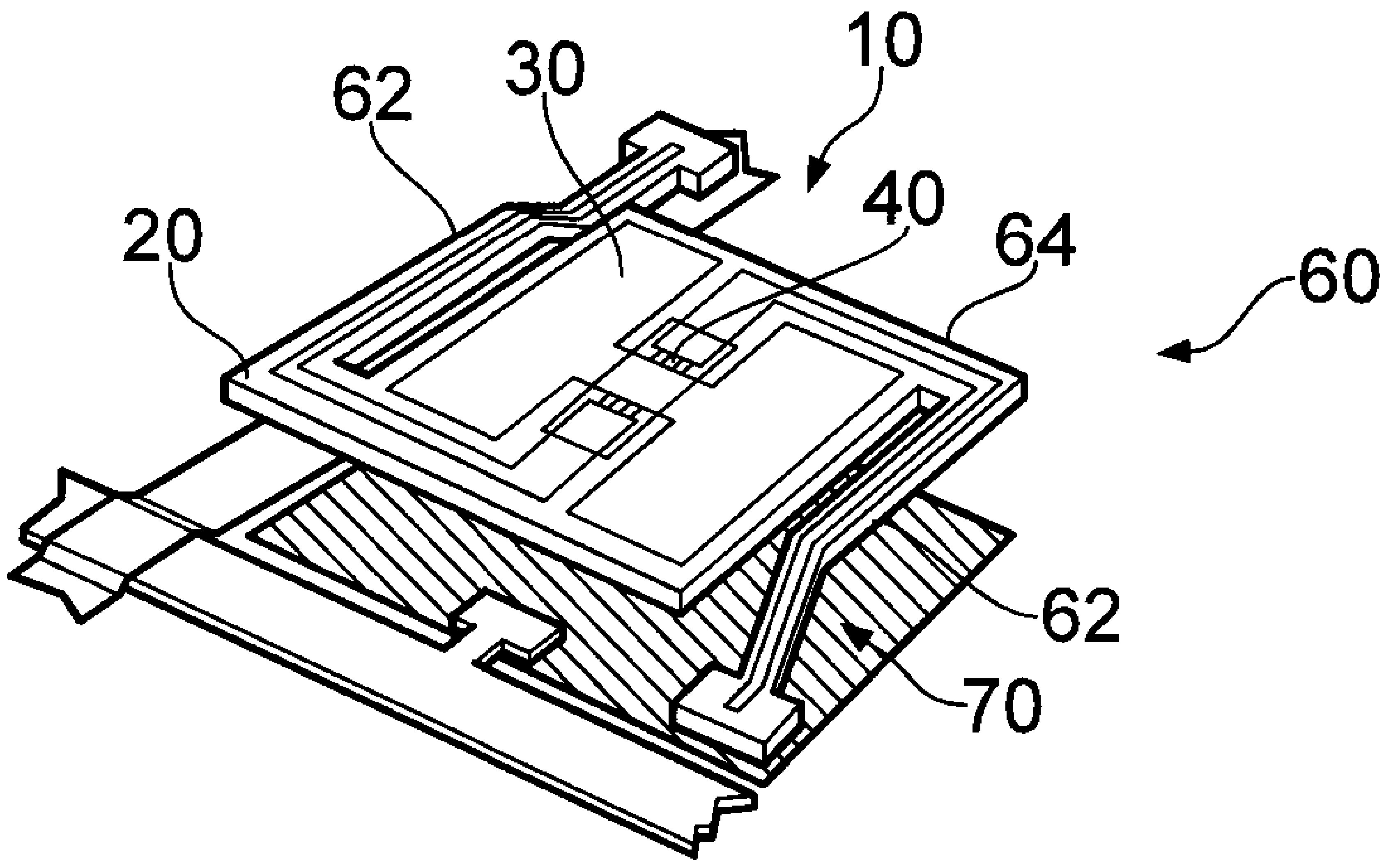

FIG. 8

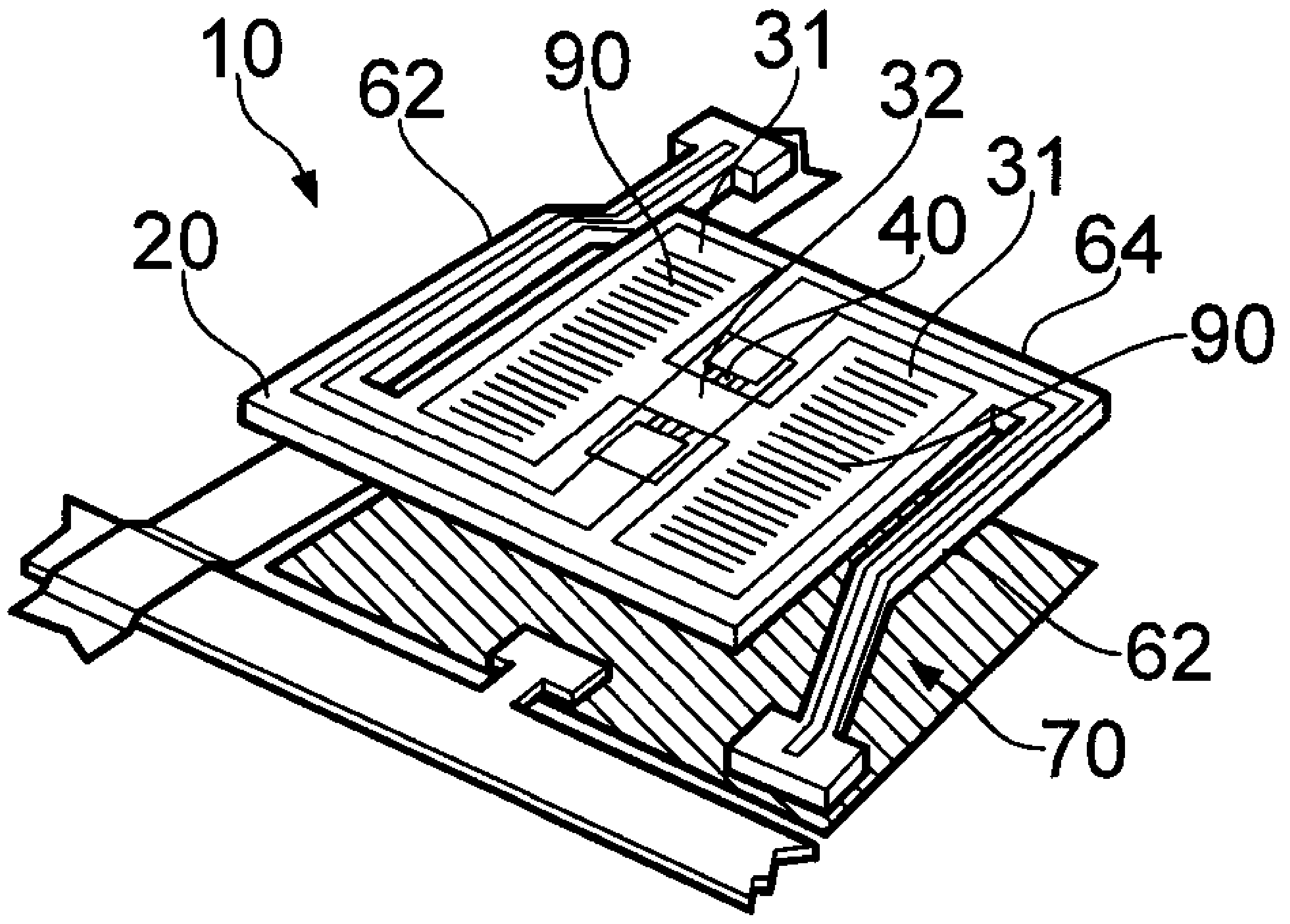

FIG. 9

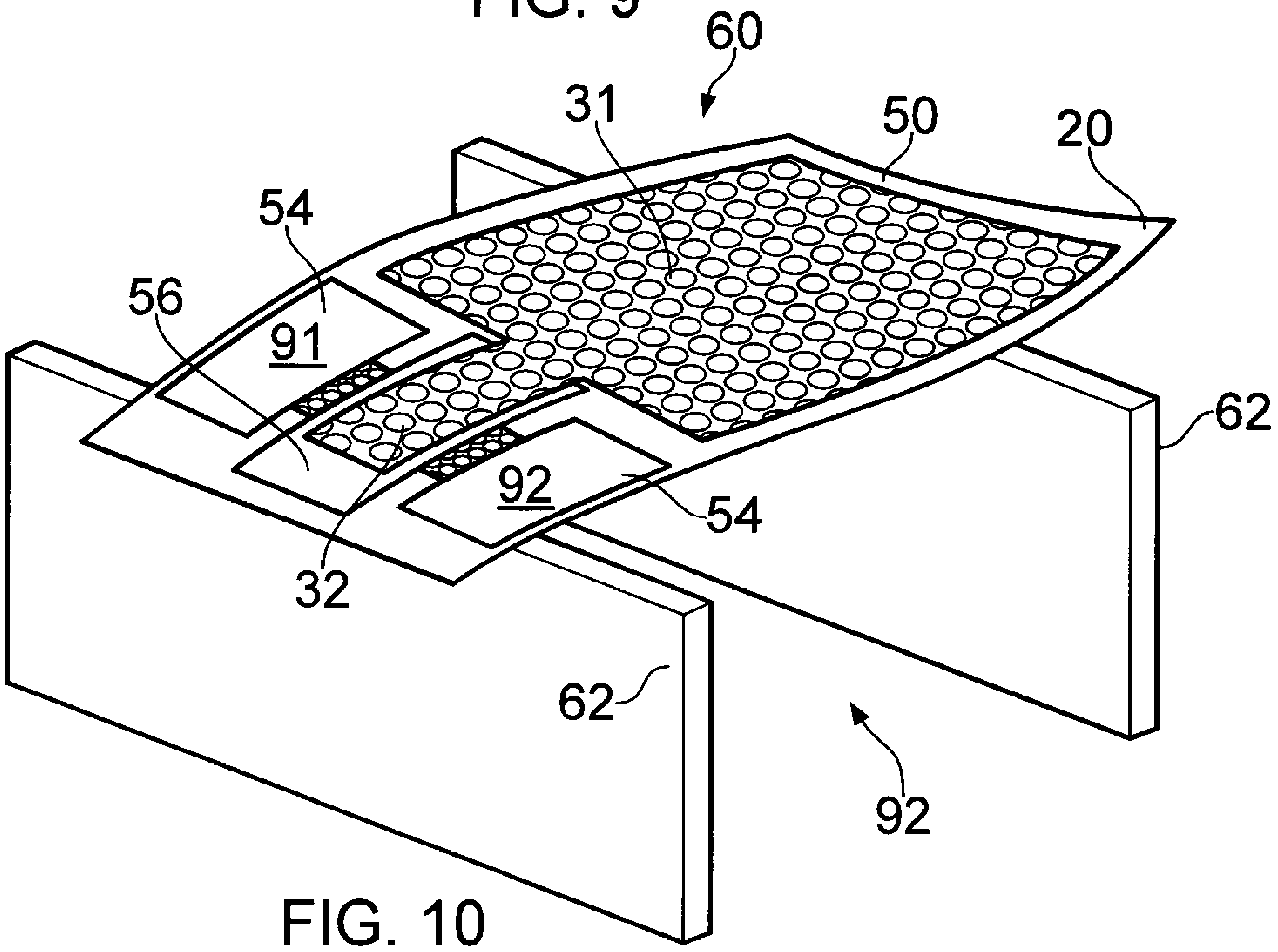

FIG. 10

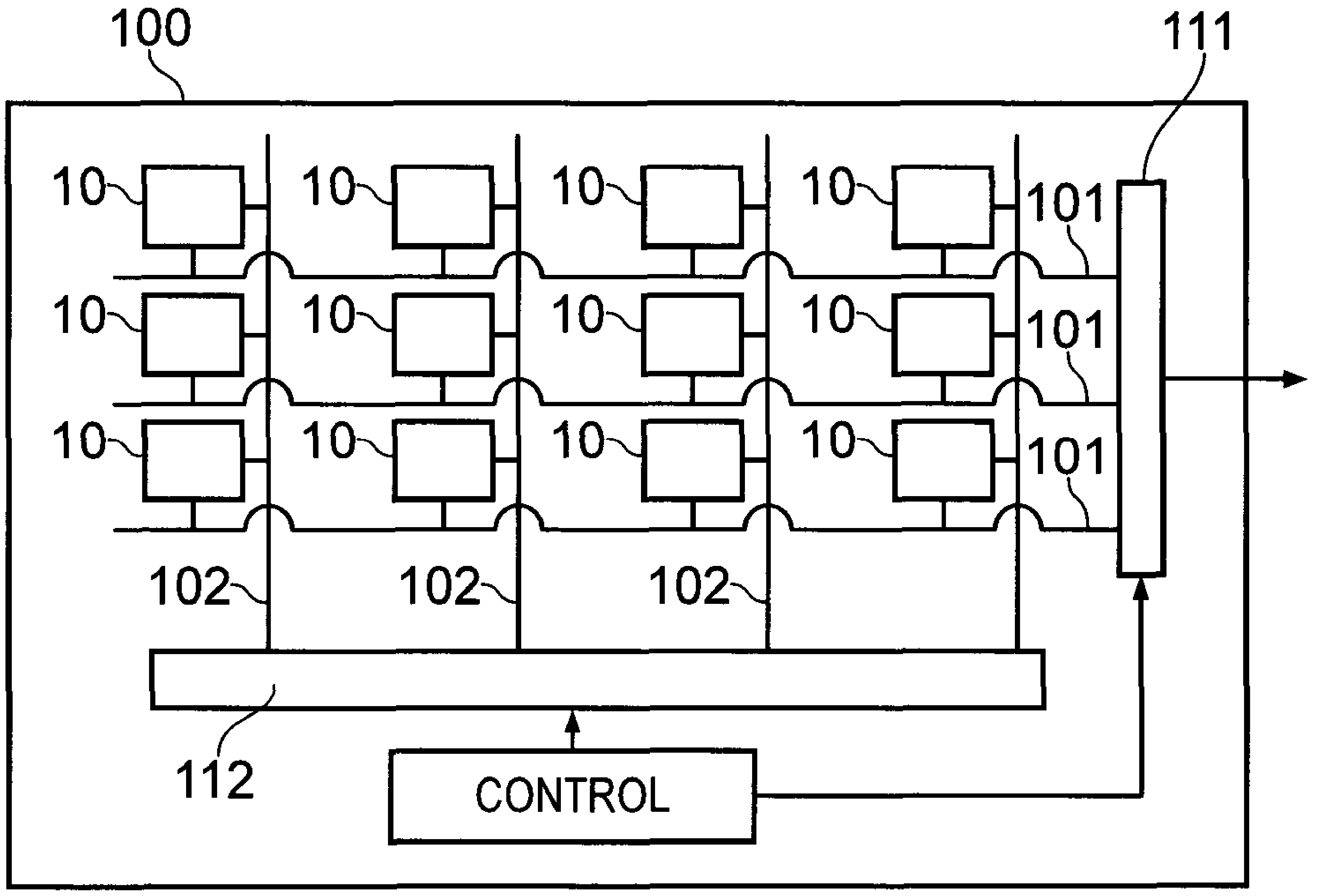

FIG. 11

SENSING APPARATUS

TECHNOLOGICAL FIELD

A sensing apparatus and in particular an electrical sensing apparatus.

BACKGROUND

A sensing apparatus senses an ambient parameter and produces an output. An electrical sensing apparatus produces an electrical output.

It is desirable to produce better sensing apparatus.

BRIEF SUMMARY

According to various, but not necessarily all, examples of one embodiment in the disclosure there may be provided an apparatus comprising: pyroelectric material; an electric field sensor; a first conductive electrode comprising a first area adjacent the pyroelectric material; a second conductive electrode comprising a second area adjacent the electric field sensor; and a conductive interconnection between the first conductive electrode and the second conductive electrode, wherein the first area of the first conductive electrode is larger than the second area of the second conductive electrode.

According to various, but not necessarily all, examples of another embodiment of the disclosure there is provided an apparatus comprising: sensing material having a polarization that changes in response to an applied actuation; an electric field sensor; a first conductive electrode comprising a first area adjacent the sensing material; a second conductive electrode comprising a second area adjacent the electric field sensor; a conductive interconnection between the first conductive electrode and the second conductive electrode, wherein the first area is larger than the second area.

In this embodiment, the sensing material may, for example, be a pyroelectric material or may be, for example, be a piezoelectric material having a polarization that changes in response to deformation.

A pyroelectric material have a polarization that changes in response to heat transfer. The heat may be transferred from incident photons.

According to various, but not necessarily all, examples of the disclosure the second conductive electrode and the conductive interconnection, in combination, form an electrically isolated or electrically isolatable amplifying electrode.

According to various, but not necessarily all, examples of the disclosure the pyroelectric material and the first conductive electrode form a first capacitor having a first electric field dependent upon a polarization of the pyroelectric material (or sensing material) and wherein the first electric field causes, at the second conductive electrode, a second electric field that is dependent upon the first electric field amplified by a ratio of the first area to the second area.

According to various, but not necessarily all, examples of the disclosure the first area is at least ten times larger than the second conductive area and optionally at least fifty times larger than the second conductive area.

According to various, but not necessarily all, examples of the disclosure the electric field sensor has a channel conductivity between a source and a drain that is dependent upon an electric field at the adjacent second conductive electrode.

According to various, but not necessarily all, examples of the disclosure the electric field sensor is an insulated gate field effect transistor, wherein the second conductive electrode provides an insulated gate.

According to various, but not necessarily all, examples of the disclosure the electric field sensor comprises graphene.

According to various, but not necessarily all, examples of the disclosure the first conductive electrode, the second conductive electrode and the conductive interconnection, in combination, are formed from a common material.

According to various, but not necessarily all, examples of the disclosure the second conductive electrode is formed from metal, semiconductor, 2D material, ionic-liquid, ionic gel.

According to various, but not necessarily all, examples of the disclosure the apparatus comprises a photon absorbing layer for absorbing photons and generating heat in or adjacent the pyroelectric material.

According to various, but not necessarily all, examples of the disclosure the photon absorbing layer overlies the pyroelectric layer and is the first conductive electrode or overlies the first conductive electrode.

According to various, but not necessarily all, examples of the disclosure the photon absorbing layer is a micro-engineered layer than operates as an antenna for absorbing electromagnetic wavelength of a particular frequency or frequencies.

According to various, but not necessarily all, examples of the disclosure the pyroelectric material (or sensing material) extends adjacent the electric field sensor and is configured to provide a third electric field, dependent upon a polarization of the pyroelectric material (or sensing material), for sensing by the electric field sensor.

According to various, but not necessarily all, examples of the disclosure, the first area of the first conductive electrode overlies a first area of the pyroelectric material; the second area of the second conductive electrode overlies a second area of the pyroelectric material; a graphene layer of the electric field sensor extends over and is in contact with the first area of the pyroelectric material and does not extend over the second area of the pyroelectric material; dielectric extends over at least the graphene layer; and

patterned conductive material overlying the first area of the pyroelectric material to form the first conductive electrode, overlying the second area of the pyroelectric material to form the second conductive electrode and overlying an area between the first area and the second area to form the interconnection. In other embodiments, the pyroelectric material may be a sensing material.

According to various, but not necessarily all, examples of the disclosure the apparatus is configured as a suspended structure.

One or more apparatuses may be housed in a device. The device may be configured to operate as a photodetector, a microblometer, an infrared camera etc.

BRIEF DESCRIPTION

For a better understanding of various examples that are useful for understanding the detailed description, reference will now be made by way of example only to the accompanying drawings in which:

FIG. **1** illustrates an example of an apparatus comprising sensing material;

FIG. **2** illustrates an equivalent circuit diagram for the apparatus illustrated in FIG. **1**;

FIG. **3** illustrates an example of an electric field sensor;

FIG. **4** illustrates a perspective view of an example of an apparatus using a electric field sensor;

FIG. **5**A illustrates a view of a transverse cross-section AB of FIG. **4** and FIG. **5**B illustrates view a transverse cross-section XY of FIG. **4**;

FIG. **6** illustrates an equivalent electrical circuit for the apparatus illustrated in FIG. **4** and FIGS. **5**A and **5**B;

FIGS. **7**A and **7**B illustrate an apparatus similar to that illustrated in FIGS. **5**A and **5**B and comprising a photon absorbing layer overlying the pyroelectric layer;

FIG. **8** illustrates an example of the apparatus configured as a suspended structure;

FIG. **9** is an apparatus comprising micro-engineered component(s);

FIG. **10** illustrates an example of an apparatus configured as a suspended structure; and

FIG. **11** illustrates a device comprising multiple apparatus.

DETAILED DESCRIPTION

This disclosure relates in general to an apparatus **10** comprising: sensing material **20** having a polarization that changes in response to an applied actuation **2**; an electric field sensor **40**; a first conductive electrode **31** comprising a first area **35** adjacent the sensing material **20**, a second conductive electrode **32** comprising a second area **36** adjacent the electric field sensor **40**, and a conductive interconnection **33** between the first conductive electrode **31** and the second conductive electrode **32**, wherein the first area **35** is larger than the second area **36**.

The sensing material **20** may be a pyroelectric material.

FIG. **1** illustrates an apparatus **10** comprising: pyroelectric material **20**; an electric field sensor **40**; a first conductive electrode **31** comprising a first area **35** adjacent the pyroelectric material **20**, a second conductive electrode **32** comprising a second area **36** adjacent the electric field sensor **40**, and a conductive interconnection **33** between the first conductive electrode **31** and the second conductive electrode **32**, wherein the first area **35** of the first conductive electrode **31** is larger than the second area **36** of the second conductive electrode **32**.

The apparatus **10** is configured to convert a response of the pyroelectric material **20** into an output electrical signal from the electric field sensor **40**.

The combination of the first conductive electrode **31**, the second conductive electrode **32** and the conductive interconnection **33** operate to amplify an electrostatic voltage at the first conductive electrode **31** to a larger electrostatic voltage at the second conductive element **32**. The electrostatic voltage at the first conductive electrode **31** is a result of polarization changes at the pyroelectric material **20** in response to a temperature change at the pyroelectric material **20**. The combination will therefore be referred to as an amplification electrode **30**.

The amplification electrode **30** may be electrically isolated or electrically isolatable. That is, it is a floating electrode that may be permanently electrically isolated or switched to become electrically isolated. The purpose of the isolation is that the amplification electrode **30** is a closed electrical circuit that conserves charge. There is no direct current path between the amplification electrode **30** and the electric field sensor **40**.

FIG. **2** illustrates an equivalent circuit diagram for the apparatus **10** illustrated in FIG. **1**.

A change in temperature at the pyroelectric material **20** causes a change in polarisation of the pyroelectric material **20**. This causes a change $\Delta\sigma$ in the charge distribution within the pyroelectric material **20** and so causes a change in the local electric field around the pyroelectric material **20**.

The pyroelectric material **20** and the first conductive electrode **31** form a first capacitor C**1**. The first capacitor C**1** has an effective area A**1** corresponding to the first area **35** of the first conductive electrode **31**. The first capacitor C**1** stores a charge Q**1** over the area A**1** and develops a voltage V**1**.

The electric field sensor **40** and the second conductive electrode **32** may form a second capacitor C**2**. The second capacitor C**2** has an effective area A**2** corresponding to the second area **36** of the second conductive electrode **32**. The second capacitor C**2** stores a charge Q**2** over the area A**2** and develops a voltage V**2**.

At a certain temperature T, the pyroelectric substrate produces a fixed amount of charge per unit area, indicated as $\sigma(T)$.

A first voltage V**1** generated at the first capacitor C**1** does not depend on the geometry of C**1** ($V1=Q1/C1$ with $Q1=\sigma(T)*A1$. If the area A**1** doubles, both Q**1** and C**1** double and V**1** stays constant.

The charge Q**1** needed at C**1** to screen the pyroelectric charge $\sigma(T)*A1$ must come from C**2**, as the amplification electrode **30** is a floating circuit with no access to an external charge reservoir. As capacitors C**1** and C**2** are in series, $Q2=Q1$ must hold at all times, hence the second voltage $V2=Q2/C2=Q1/C2=V1*C1/C2$.

The second voltage V**2** scales with the capacitance ratio C**1**/C**2**. It is therefore desirable for $C1>>C2$, this may be achieved by making the first area A**1** larger than the second area A**2**.

It may also be improved or maintained by having the capacitive coupling greater (or not significantly worse) for the first capacitor C**1** than the second capacitor C**2**.

The first area A**1** may be at least ten times larger than the second area A**2** and optionally at least fifty times larger than the second area A**2**.

Thus pyroelectric material **20** and the first conductive electrode **31** form a first capacitor C**1** having a first electric field dependent upon a polarization of the pyroelectric material. The first electric field causes, at the second conductive electrode **32**, a second electric field that is dependent upon the first electric field amplified by a ratio of the first area to the second area.

The pyroelectric material **20** may comprise any suitable material which provides a change in charge distribution in response a temperature change. Examples of suitable materials include Lead Zirconate Titanate (PZT), Lithium Tantalate ($LiTaO_3$), Lithium Niobate ($LiNbO_3$), Strontium Barium Niobate ($SrBaNb_2O_6$), Gallium Nitride (GaN), Caesium Nitrate ($CsNO_3$), polymers such as polyvinyl fluoride or any other material.

In some examples the pyroelectric material **20** may also be deformable and/or transparent.

The amplification electrode **30** may be formed as separated interconnected components or as a single integral component, for example, as a patterned layer of the same material.

The amplification electrode **30** or parts of the amplification electrode **30** may be formed from metal, semiconductor, 2D material, ionic-liquid, ionic gel.

In some examples the amplification electrode **30** may also be deformable and/or transparent.

The apparatus **10** has a large thermal coefficient of resistance (TCR) and may be used to detect minute changes in temperature.

FIG. **3** illustrates an example of an electric field sensor **40**. In this example, but not necessarily all examples the electric field sensor **40** is a transconductance electric field sensor.

The electric field sensor **40** comprises a channel **43** between a source **41** and a drain **42**. The channel **43** has an electrical conductivity that is dependent upon an electric field at the adjacent second conductive electrode **32**.

The channel **43** is electrically insulated from the amplification electrode **30**. This insulation may arise from the use of an ion-conducting material for the amplification electrode **30** as opposed to an electron-conducting material. Alternatively, where an electron conducting material is used for the amplification electrode **30** an electrically insulating layer such as a dielectric may be provided between the amplification electrode **30** and the electric field sensor **40**.

The electric current through the channel **43** between source **41** and drain **42** is dependent on the second voltage **V2** at the second conductive electrode **32**, which is dependent upon the ratio of the first area **35** to the second area **36** and dependent upon the first voltage **V1** generated at the first conductive electrode **31** by a change in polarization of the pyroelectric material **20**.

FIG. **3** illustrates an insulated-gate electric field sensor **40**. The second conductive electrode **32** forms a gate that is insulated from the channel **43** of the electric field sensor **40** by, in this example, a dielectric layer **44**. The insulated-gate electric field sensor **40** operates as an insulated-gate field-effect transistor (IGFET). Although an IGFET is used as an electric field sensor **40**, other electric field sensors **40** may be used.

In some but not necessarily all examples, the channel **43** may be a layer of graphene. The layer of graphene may be a monolayer. The source **41**, drain **42** and channel **43** may be different portions of the same layer of graphene. Graphene responds to local electric fields by varying its conductivity like a semiconductor. In other examples different materials may be used. The materials used in the electric field sensor **40** may be any transconductive material which has an electrical conductivity which is dependent upon the local electric field.

In some examples the electric field sensor **40** may also be deformable and/or transparent.

FIG. **4** illustrates a perspective view of an apparatus **10**, as previously described using a electric field sensor **40** as illustrated in FIG. **3**. FIG. **5**A illustrates a view of a transverse cross-section AB and FIG. **5**B illustrates view a transverse cross-section XY.

In this example, the pyroelectric material **20** forms an underlying substrate **50**. The electric field sensor **40** is formed on top of the pyroelectric substrate **50**. The electric field sensor **40** comprises a channel **43** between a source **41** and a drain **42**. The source **41**, the channel **43** and the drain **42** may be provided by a layer of graphene **52**.

Conductive terminals **54** may be applied to the source **41** and, separately, to the drain **42**.

A dielectric layer **56** extends over at least the channel **43** of the graphene **52**. The dielectric layer **56** will prevent electrical connection between the amplification electrode **30** and the graphene **52**.

The amplification electrode **30** extends through a first area **35** to form the first conductive electrode **31** in contact with the pyroelectric substrate **50**, extends through a second area **36** to form the second conductive electrode **32** separated by the dielectric layer **56** from the channel **43**, and extends through an area between the first and second conductive elements **31**, **32** to form the conductive interconnection **33**.

The amplification electrode **30** may be patterned conductive material

In this example, the first conductive electrode **31** contacts the pyroelectric substrate **50**. The contacting portion of the first conductive electrode **31** is designated as a first area **35** of the first conductive electrode **31**. The equivalent contacting portion of the pyroelectric substrate **50** is designated a first area **25** of the pyroelectric material **20**.

In this example, the channel **43** of the electric-field sensor **40** contacts the pyroelectric substrate **50** over a second area **27** of the pyroelectric material **20**.

The second area **36** of the second conductive electrode **32** overlies the second area **27** of the pyroelectric material **20** but is separated from the pyroelectric material **20** by the graphene channel **43** and the gate dielectric **44**.

The pyroelectric material **20** in this example is an insulator with no free charge. Therefore although the pyroelectric material **20** contacts the first conductive electrode **31** and the electric field sensor **40**, it also electrically insulates the first conductive electrode **31** and the electric field sensor **40**.

The channel **43** has an electrical conductivity that is dependent upon a second electric field at the adjacent non-contacting second conductive electrode **32** (top-gate) and that is dependent upon a third electric field at the adjacent and contacting second area **27** of the pyroelectric material **20** (bottom-gate).

Although graphene is used to define the channel **43**, other materials may be used. Any material which may be manufactured in a thin film and positioned in contact with pyroelectric material **20** and which has an electrical conductivity which is dependent upon the local electric field may be used.

A short and narrow graphene channel **43** uses only a fraction of the available area of the pyroelectric substrate **50**. It may have a resistance of ~1 kOhm. This is low enough to provide a good read-out, but still dominant over the series resistance of the contacts **54** that tend to decrease the sensitivity.

FIG. **6** illustrates an equivalent electrical circuit for the apparatus **10** as illustrated in FIG. **4** and FIGS. **5**A and **5**B. It is similar to the equivalent circuit illustrated in FIG. **2**. However, it differs in that the second area **27** of the pyroelectric material **20** forms a third capacitor C**3**, adjacent the electric field sensor **40**, that generates a third electric field. The electric field sensor **40** senses a second electric field generated by the second capacitor C**2** and a third electric field generated by the third capacitor C**3**.

In this example, absorption of photons **2** by the pyroelectric substrate or other parts of the apparatus **10** result in a temperature increase at the pyroelectric material **20**.

The photons **2** absorbed by the apparatus **10** that result in a temperature increase in the pyroelectric material **20** may be photons in the infrared region of the electromagnetic spectrum. For example, the photons may have wavelengths between 5-14 μm. Detection of the infrared photons may be used to determine a temperature of the source of the photons or to image a source of the infrared photons.

In some examples the absorbed photons may be outside the infrared region of the spectrum. For example the incident photons may be in the visible region of the spectrum.

The apparatus **10** may comprise a photon absorbing layer for absorbing photons and generating heat the pyroelectric material **20**. The photon absorbing layer may be formed from the pyroelectric material **20** or another part of the apparatus **10**.

In some examples the pyroelectric material **20** may be a poor absorber of electromagnetic radiation and/or a poor thermal conductor. This may result in only a small change in temperature of the pyroelectric material **20** for a given amount of incident electromagnetic radiation.

In some but not necessarily all embodiments, the absorption of photons by the pyroelectric material **20** may be increased by micro-engineering the pyroelectric material **20** to form a photon absorbing layer that operates as an antenna for absorbing electromagnetic wavelength of a particular frequency or frequencies.

In some but not necessarily all examples, the apparatus **10** may comprise a photon absorbing layer **90** for absorbing photons and generating heat at the pyroelectric material **20** that is additional to the pyroelectric material **20**. In the example of FIGS. **7**A and **7**B, the apparatus **10** is the same as the apparatus **10** illustrated in FIGS. **5**A and **5**B except that a photon absorbing layer **90** overlies the pyroelectric layer **20** and the amplifying electrode **30**, at least the first conductive electrode **31** of the amplifying electrode **30**. The photon absorbing layer **90** may be an infrared-absorbing polymer or dye.

FIG. **8** illustrates an example of the apparatus **10**, as described previously, configured as a suspended structure **60**.

The suspended structure **60** is suspended above a lower substrate **70** via supports **62**.

The suspended structure **60** may be formed by depositing successive patterned layers of a first material and a second material. The pattern of the second material builds up over multiple layers to form the suspended structure **60** surrounded by the first material. Selective removal of the first material and not the second material produces the suspended structure **60** as a free-standing structure with a void underneath a platform **64** suspended by supports **62**.

The apparatus **10** may be defined on the upper surface of the suspended platform **64**. Electrical interconnects between the apparatus **10** and the lower substrate **70** are formed on the supports **62**.

The suspended platform **64** ensures a low thermal capacity as the thermal conductivity between apparatus **10** and lower substrate **70** is low. This ensures a maximum change in temperature for fixed incoming radiation. Some transfer of energy from the apparatus **10** occurs e.g. via the electrical interconnects to control the integration time of the sensor.

FIG. **9** is an apparatus **10** similar to that illustrated in FIG. **8**, however, the apparatus comprises a micro-engineered first conductive electrode **31** that operates as an antenna for absorbing photons of a particular frequency or frequencies. The micro-engineered first conductive electrode **31** is a photon absorbing layer **90**.

FIG. **10** illustrates an example of an apparatus similar to those described with reference to FIGS. **1** to **7**. FIG. **10** illustrates an example of the apparatus **10** configured as a suspended structure **60**.

In this example, the apparatus **10** is similar to the apparatus **10** described with reference to FIGS. **4** and **5**A and **5**B. However, in this example, components of the apparatus **10** are formed from two-dimensional (2D) materials.

The pyroelectric substrate **50** is a 2D material suspended over a trench **92**.

The source **41**, channel **43** and drain **42** of the electric field sensor **40** are formed from 2D material, for example, a monolayer of graphene.

The amplifying electrode **30** comprising the first conductive element **31**, the second conductive element **32** and the conductive interconnection **33** are formed from a single piece of 2D material, for example, a monolayer of graphene.

Suitable pyroelectric 2D materials include, but are not limited to: BN, MoS2, WSe2, covalently functionalized graphene (e.g., Fluorographene).

The use of stiff 2D materials allows the simple creation of a suspended structure **60**.

FIG. **11** illustrates a device **100** comprising multiple apparatus **10** as previously described. The device **100** may, for example, be configured to operate as a photodetector, a microblometer, an infrared camera, a thermal imaging device or a heat sensor.

The device **100** comprises a plurality of apparatus **10**. In the particular example of FIG. **11** twelve apparatus **10** are provided within the device **100**. It is to be appreciated that any number of apparatus **10** may be provided in other examples.

The different apparatus **10** may be configured to sense photons of the same frequency or band of frequencies or to detect photons of different frequencies or bands of frequencies.

In some examples the device **100** may comprise some apparatus **10** which are configured to detect incident photons in the infrared region of the spectrum and some which are configured to detect incident photons in the visible region of the spectrum. This may enable the heating effect of the infra red radiation to be measured separately to the heating effect of the radiation in the visible region of the spectrum. This may enable the device **100** to be used as a thermal sensor even in daylight or when there a high levels of incident electromagnetic radiation in the visible region of the spectrum.

In the example illustrated the apparatus **10** are arranged as a regular array in rows and columns.

Each apparatus **10** in a row is connected to a particular row address line **101**. Each row has a different row address line **101**. Row addressing circuitry **111** enables one of the row address lines to be enabled at a time.

Each apparatus **10** in a column is connected to a particular column address line **102**. Each column has a different column address line **102**. Column addressing circuitry **112** enables one of the column address lines to be enabled at a time.

The electric field sensor **40** of a particular apparatus **10** may be read by enabling the particular column address line **102** the apparatus **10** is connected to and the particular row address line **101** the apparatus is connected to. The output from the electric field sensor **40** is indicative of the local temperature at that apparatus **10** which may be caused by incident photons.

In the foregoing description emphasis has been placed on an example that uses pyroelectric material **20** as a sensing material. However, other sensing materials may be used that have a polarization that changes in response to an applied actuation.

In the examples above, the sensing material **20** was pyroelectric material and the applied actuation was electromagnetic radiation.

However, in other examples, the sensing material **20** may be a piezoelectric material and the applied actuation may be deformation.

In the above description the term coupled means operationally coupled and any number or combination of intervening elements can exist including no intervening elements.

The term “comprise” is used in this document with an inclusive not an exclusive meaning. That is any reference to

X comprising Y indicates that X may comprise only one Y or may comprise more than one Y. If it is intended to use "comprise" with an exclusive meaning then it will be made clear in the context by referring to "comprising only one . . . " or by using "consisting".

In this brief description, reference has been made to various examples. The description of features or functions in relation to an example indicates that those features or functions are present in that example. The use of the term "example" or "for example" or "may" in the text denotes, whether explicitly stated or not, that such features or functions are present in at least the described example, whether described as an example or not, and that they can be, but are not necessarily, present in some of or all other examples. Thus "example", "for example" or "may" refers to a particular instance in a class of examples. A property of the instance can be a property of only that instance or a property of the class or a property of a sub-class of the class that includes some but not all of the instances in the class.

Although embodiments of the present invention have been described in the preceding paragraphs with reference to various examples, it should be appreciated that modifications to the examples given can be made without departing from the scope of the invention as claimed.

Features described in the preceding description may be used in combinations other than the combinations explicitly described.

Although functions have been described with reference to certain features, those functions may be performable by other features whether described or not.

Although features have been described with reference to certain embodiments, those features may also be present in other embodiments whether described or not.

Whilst endeavoring in the foregoing specification to draw attention to those features of the invention believed to be of particular importance it should be understood that the Applicant claims protection in respect of any patentable feature or combination of features hereinbefore referred to and/or shown in the drawings whether or not particular emphasis has been placed thereon.

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The invention claimed is:

1. An apparatus comprising:

a pyroelectric material;

a patterned conductive material overlying a first area of the pyroelectric material to form a first conductive electrode, and

an electric field sensor which comprises:

a channel between a source and a drain,

a dielectric layer which extends over the channel,

a gate which is insulated from the channel by the dielectric layer,

wherein

the channel contacts the pyroelectric material in a second area of the pyroelectric material, and

the patterned conductive material overlies the second area of the pyroelectric material to form a second conductive electrode which forms the gate in the electric field sensor,

wherein the first area is larger than the second area.

2. An apparatus as claimed in claim **1**, wherein the pyroelectric material and the first conductive electrode form a first capacitor having a first electric field dependent upon a polarization of the pyroelectric material and wherein the first electric field causes, at the second conductive electrode, a second electric field that is dependent upon the first electric field amplified by a ratio of the first area to the second area.

3. An apparatus as claimed in claim **1**, wherein the first area is at least ten times larger than the second area.

4. An apparatus as claimed in claim **1**, wherein the channel comprises a layer of graphene.

5. An apparatus as claimed in claim **1**, wherein a photon absorbing layer overlies the pyroelectric layer and comprises the first conductive electrode or overlies the first conductive electrode.

6. An apparatus as claimed in claim **5**, wherein the photon absorbing layer is a micro-engineered layer that operates as an antenna for absorbing electromagnetic wavelength of a particular frequency or frequencies.

7. An apparatus as claimed in claim **1** configured as a suspended structure.

8. A device comprising multiple apparatuses as claimed in claim **1**, wherein the device is configured to operate as a photodetector, a microbolometer, or an infrared camera.

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